# §1. Design Studies on Helical Reactor FFHR

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Collaboration work based on the LHD project has made great progress in design studies on the Force-Free Helical Reactor, FFHR, which is a demo-relevant helical-type D-T fusion reactor. The main feature of FFHR is force-free-like configuration of helical coils, which simplifies the coil supporting structure with a high magnetic field instead of high plasma beta. The other feature is the selection of molten-salt Flibe as a self-cooling tritium breeder for the main reason of inherent safety. Our present activity is at the first stage in Phase I for the concept definition.

In order to increase $B_0$, the force-free-like concept in FFHR-1($l$ =3, R=20m)[1,2] is applied again in the LHD-type compact system FFHR-2[3] as shown in Table.1, which is 2.5 times larger than LHD but a half of FFHR-1. By reducing the helical pitch parameter, $\gamma=(m/l)(a_c/R)$, from 1.25 in LHD to 1.15, the averaged minor radius hoop force on the helical coils $<f_a>$ normalized by $B_0I_H$ is reduced to 73% of LHD as shown in Fig.1. At the same time, the clearance $\delta L$ increases about 5 times of that in LHD. In FFHR-1, the cylindrical supporting structure was proposed to make large maintenance holes at top and bottom regions of the helical coils, where the FEM analyses of supporting structures resulted in the maximum stress below 650 MPa within the allowable stress of 316 LN-type stainless steel. Therefore, in FFHR-2, the cylindrical supporting structure is adopted again to use a high toroidal field $B_0$ of 10T with innovative SC materials such as $Nb_3Al$. It should be pronounced that, as listed in Table 1, the design $\gamma$ of 1.15 in FFHR-2 is within the experimental range in LHD, where the averaged minor radius $a_c$ of the helical coil can be varied due to the separately controllable 3-layered helical coil.

Heat exchange from Flibe to He gas has been investigated under the merit of high temperature operation of Flibe. By introducing an advanced concept of multi-expansion above the solidification temperature of Flibe and multi-compression at 35°C, fairly high cycle efficiency is obtained as shown in Table 2. Here the control of tritium permeation is the next major issue to be solved in this system.

[1] A.Sagara et al, Fusion Engrg. Design.29 (1995) 51.
[2] A.Sagara and O.Motojima, Fusion Technology 34 (1998) 1167.
[3] A.Sagara, et al, 17th IAEA Fusion Energy Conf. 1998, Yokohama, FTP-3.

Table 1  LHD and FFHR design parameters.

| Parameters | LHD | FFHR-1 | FFHR-2 |
|---|---|---|---|
| major radius : R | 3.9 | 20 | 10 m |
| av. plasma radius : $<a_p>$ | < 0.65 | 2 | 1.2 m |
| fusion power : Pf (GW) | - | 3 | 1 GW |
| external heating power : Pex | < 20 | 100 | 100 MW |
| neutron wall loading : Pn | - | 1.5 | 1.5 MW/m2 |
| toroidal field on axis : $B_0$ | 4 | 12 | 10 T |
| average beta : $<\beta>$ | > 5 | 0.7 | 1.8 % |
| enhancement factor of $\tau_{LHD}$ | | 1.5 | 2.5 |
| plasma density : ne(0) | 1.E20 | 2.E20 | 2.8E20 m-3 |
| plasma temperature : Te(0) | > 10 | 22 | 27 keV |
| effective ion charge : Zeff | | 1.5 | 1.5 |
| alpha heating efficiency : h$\alpha$ | - | 0.7 | 0.7 |
| alpha density fraction : f$\alpha$ | - | 0.05 | 0.05 |
| synchrotron reflectivity : Reff | - | 0.9 | 0.9 |
| hole fraction : fh | - | 0.1 | 0.1 |
| av. heat load on divertor | < 10 | 1.6 | 1.5MW/m2 |
| number of pole : $\ell$ | 2 | 3 | 2 |
| toroidal pitch number : m | 10 | 18 | 10 |
| pitch parameter : $\gamma$ | 1.12<1.25<1.37 | 1 | 1.15 |
| coil modulation : $\alpha$ | + 0.1 | 0 | + 0.1 |
| av. helical coil radius : $<a_c>$ | 0.975 | 3.33 | 2.30 m |
| coil to plasma clearance : $\delta L$ | 0.03 | 1.1 | 0.70 ~ 1.25 m |
| coil current : $I_H$ | 7.8 | 66.6 | 50 MA/coil |
| coil current density : J | (53) | 27 | 25 A/mm2 |
| max. field on coils : Bmax | (9.2) | 16 | 13 T |
| stored magnetic energy | 1.64 | 1290 | 147 GJ. |
| construction cost | 50 Byen | | |

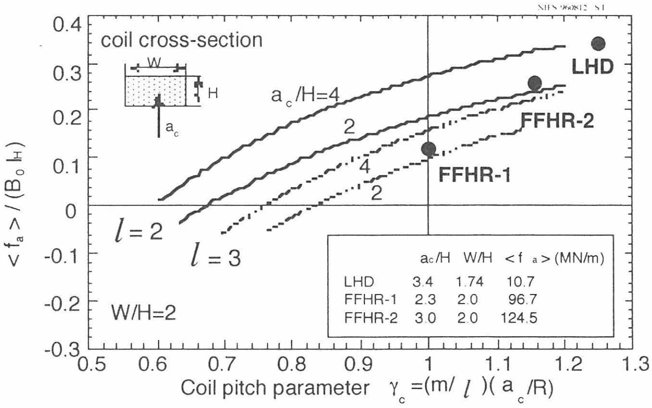


Fig. 1  The averaged minor radius hoop force on helical coils $<f_a>$ normalized by $B_0I_H$.

Table 2  Heat exchange efficiency for He gas.

| Number of compression stage | Number of expansion stage | System max. temp | Total comp ratio | Cycle efficiency |
|---|---|---|---|---|
| 2 | 1 | 850°C | 3.2 | 44.3% |
| 2 | 1 | 530°C | 1.4 | 26.6% |
| 2 | 2 | 530°C | 2.0 | 35.5% |
| 2 | 3 | 530°C | 2.9 | 35.5% |
| 2 | 4 | 530°C | 4.3 | 34.2% |
| 3 | 2 | 530°C | 2.0 | 36.8% |
| 3 | 3 | 530°C | 2.9 | 37.6% |
| 3 | 4 | 530°C | 4.3 | 37.1% |
| 3 | 2 | 650°C | 4.4 | 41.9% |
| 3 | 3 | 650°C | 9.4 | 39.9% |
| 3 | 4 | 650°C | 20.2 | 37.2% |